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(54) **METHOD AND APPARATUS TO MAXIMIZE RETURN ON INVESTMENT IN HYBRID CLOUD ENVIRONMENT**

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This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

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G06F 15/16	(2006.01)
H04L 29/08	(2006.01)
G06F 9/48	(2006.01)
G06F 9/50	(2006.01)
H04L 29/06	(2006.01)

(52) **U.S. Cl.**
CPC ***H04L 67/1008*** (2013.01); ***G06F 9/4856*** (2013.01); ***G06F 9/5072*** (2013.01); ***H04L 67/42*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 67/1008
USPC 709/201, 203, 223
See application file for complete search history.

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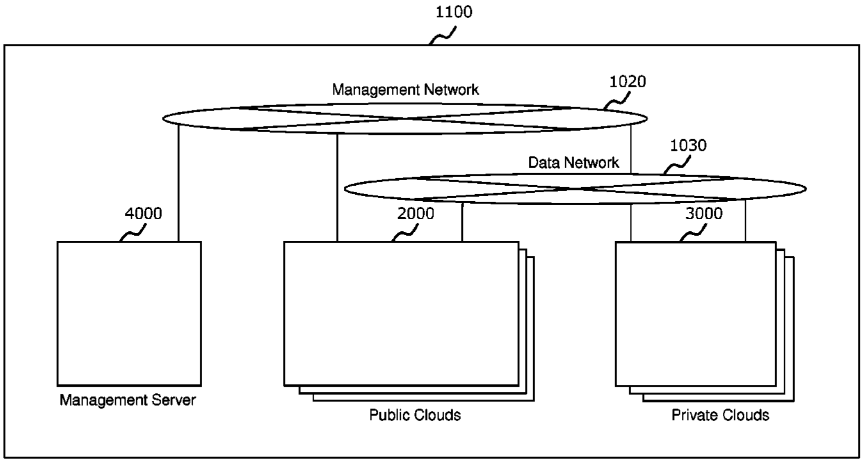
(57) **ABSTRACT**

Exemplary embodiments improve return on investment in hybrid cloud environment. In one embodiment, a computer comprises: a memory; and a processor operable to manage two types of clouds, which are private and public clouds, by using information stored in the memory, and to manage migration of a set of an application and a data between a first type of clouds and a second type of clouds of the two types of clouds, the application running on a server of the first type of clouds, the data to be read or written by the application and being stored in a storage system of the first type of clouds. The processor manages the migration of the set of the application and the data between the first type of clouds and the second type of clouds based on resource utilization of resources including at least one of the server or the storage system.

16 Claims, 17 Drawing Sheets



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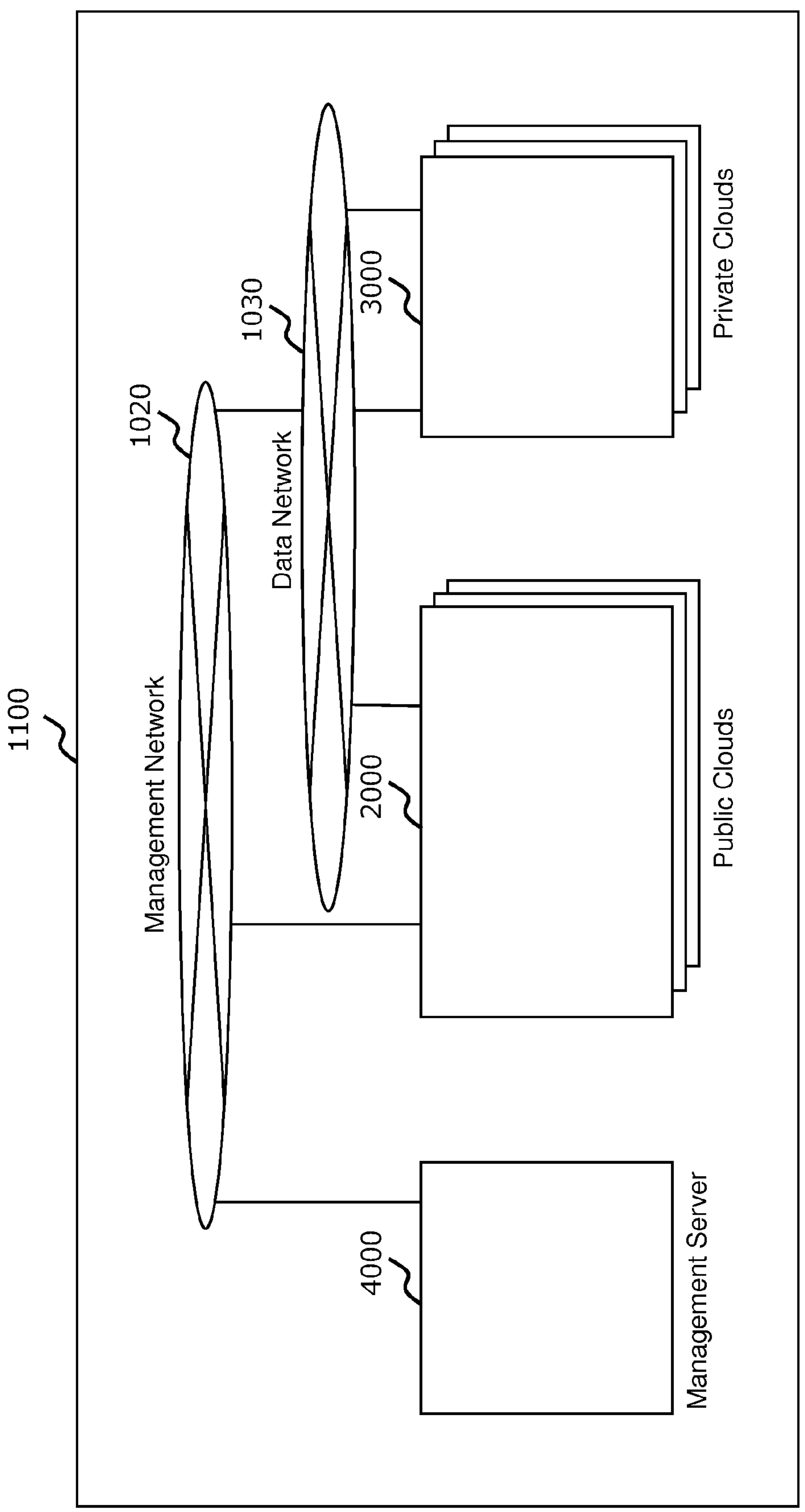

1100
Management Network
1020
Data Network
1030
3000
Private Clouds
2000
Public Clouds
4000
Management Server

Fig. 1

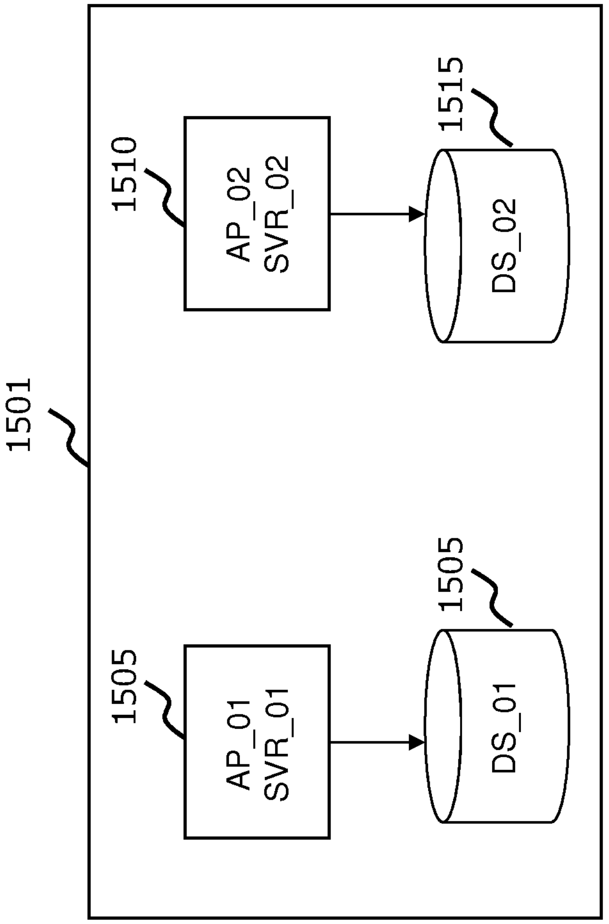


Fig. 1-A

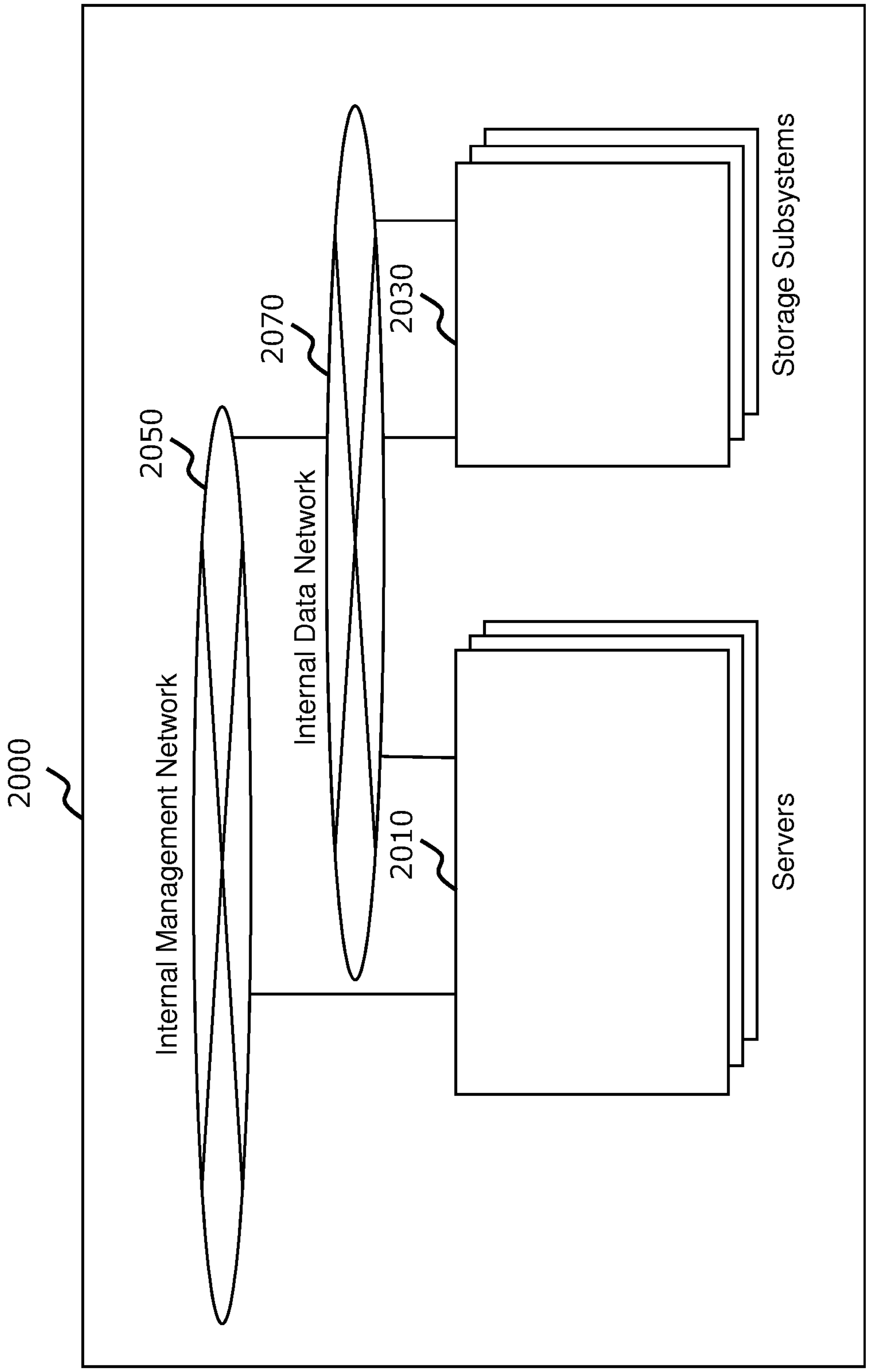

2000
Internal Management Network
2050
Internal Data Network
2070
2010
2030
Servers
Storage Subsystems

Fig. 2

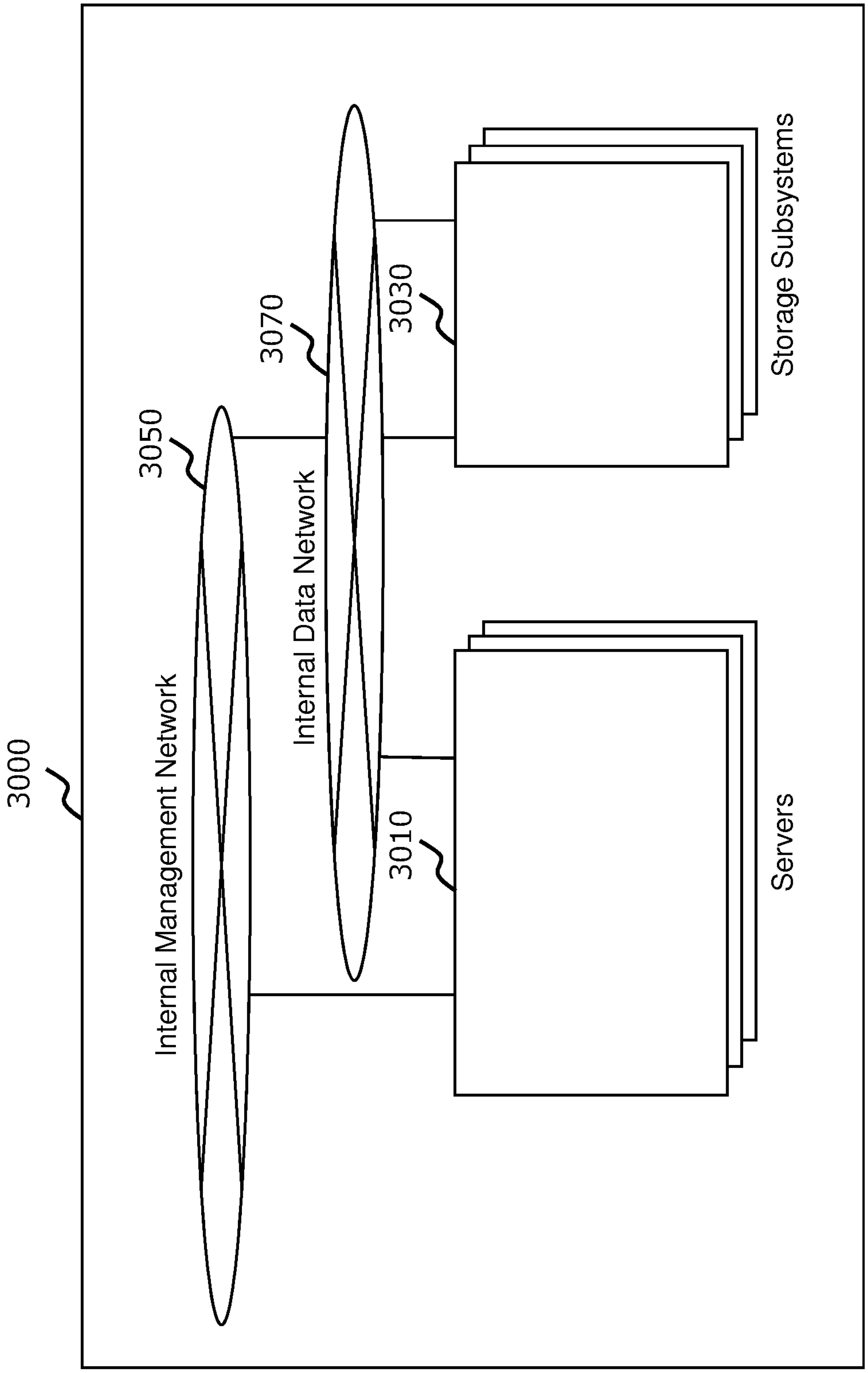

3000
Internal Management Network
3050
Internal Data Network
3070
3010
3030
Servers
Storage Subsystems

Fig. 3

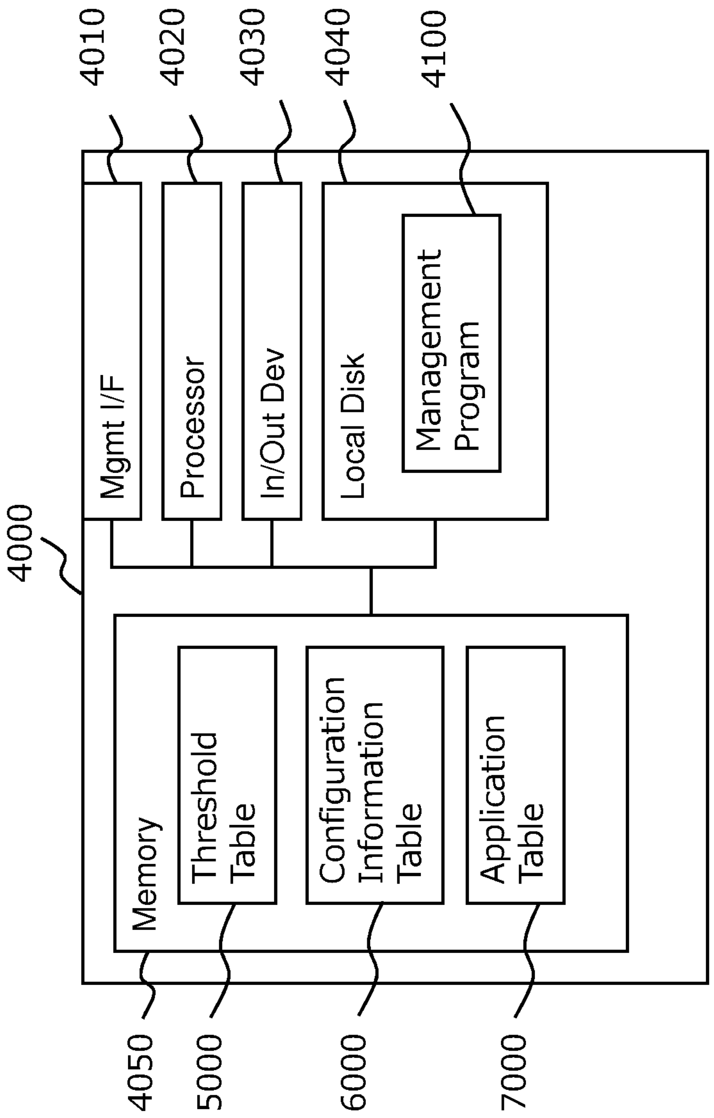
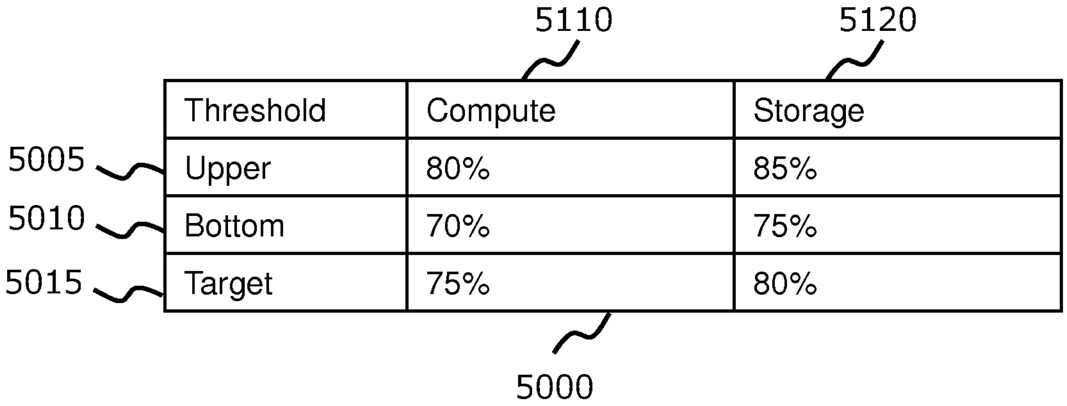
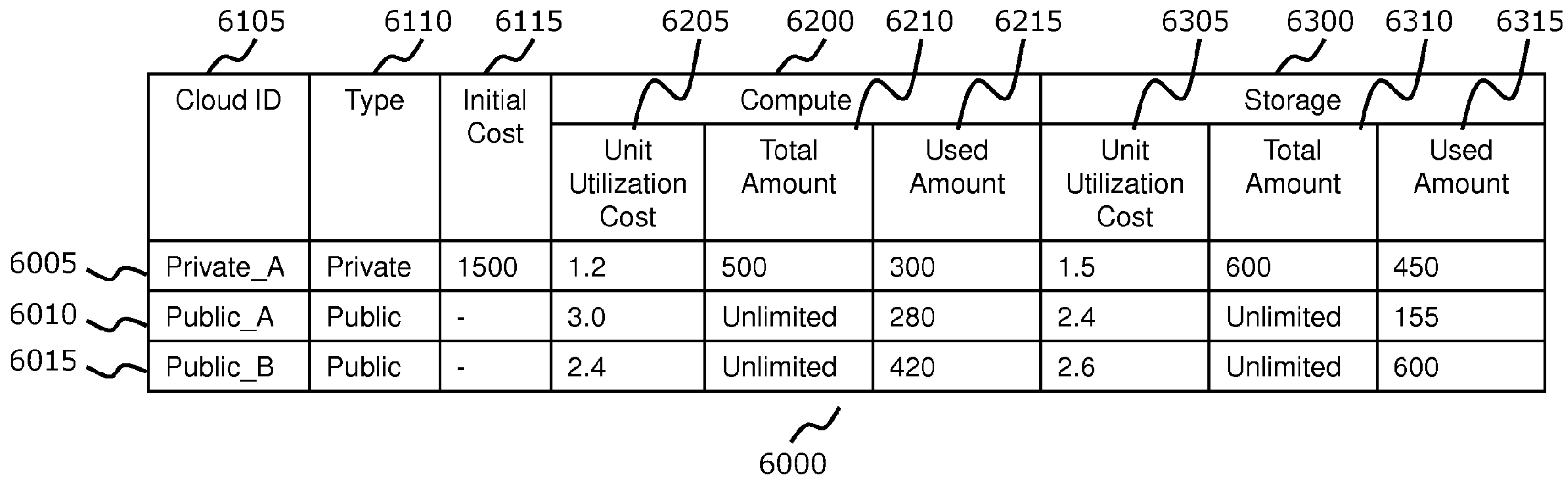

4000
4010
4020
4030
4040
4100
Mgmt I/F
Processor
In/Out Dev
Local Disk
Management Program
Memory
Threshold Table
Configuration Information Table
Application Table
4050
5000
6000
7000

Fig. 4


5110
5120
5005
5010
5015
5000

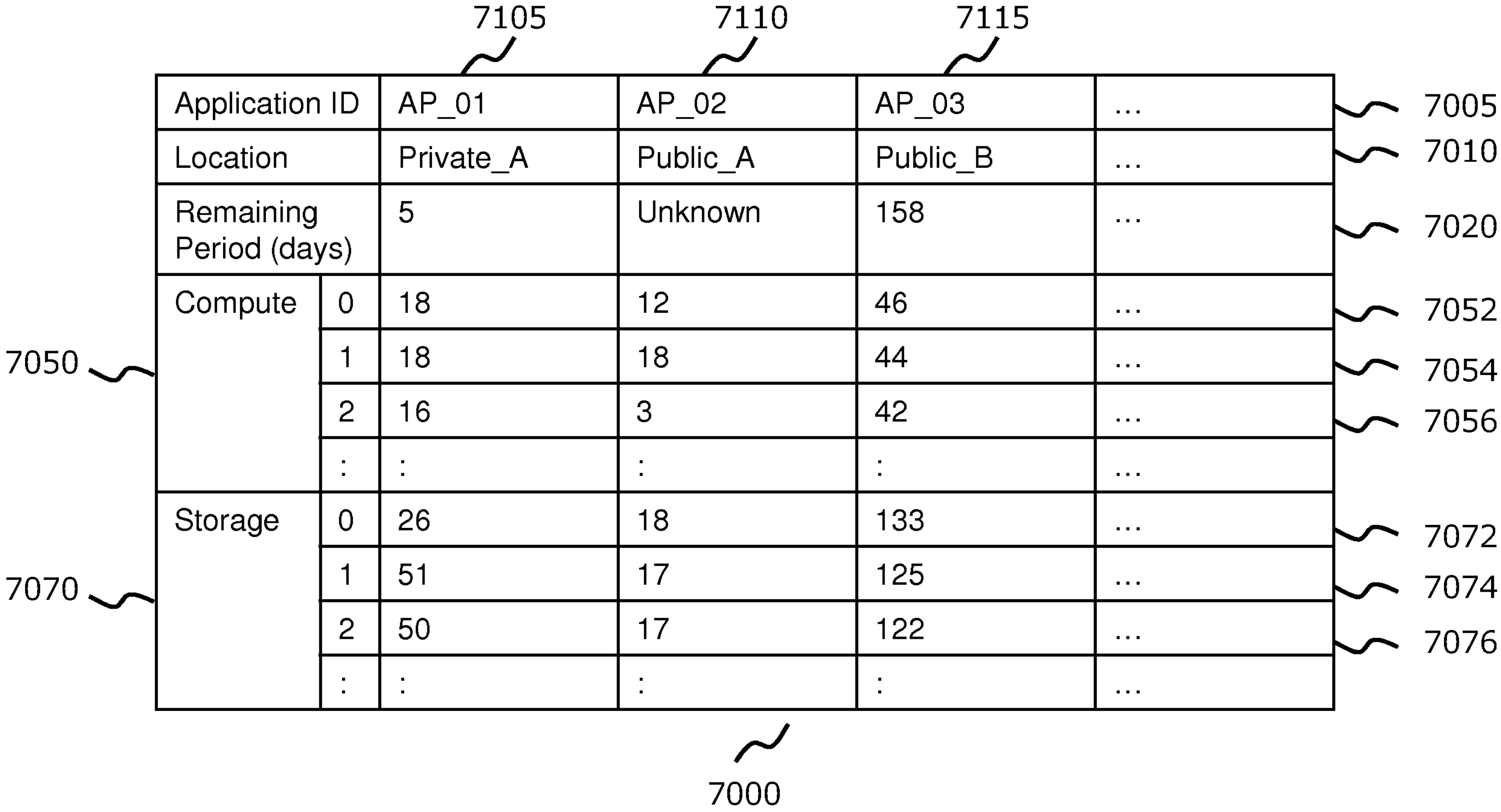
Threshold	Compute	Storage
Upper	80%	85%
Bottom	70%	75%
Target	75%	80%

Fig. 5


6105
6110
6115
6205
6200
6210
6215
6305
6300
6310
6315
6005
6010
6015
6000

Cloud ID	Type	Initial Cost	Compute			Storage		
			Unit Utilization Cost	Total Amount	Used Amount	Unit Utilization Cost	Total Amount	Used Amount
Private_A	Private	1500	1.2	500	300	1.5	600	450
Public_A	Public	-	3.0	Unlimited	280	2.4	Unlimited	155
Public_B	Public	-	2.4	Unlimited	420	2.6	Unlimited	600

Fig. 6



Application ID		AP_01	AP_02	AP_03	…
Location		Private_A	Public_A	Public_B	…
Remaining Period (days)		5	Unknown	158	…
Compute	0	18	12	46	…
	1	18	18	44	…
	2	16	3	42	…
	:	:	:	:	…
Storage	0	26	18	133	…
	1	51	17	125	…
	2	50	17	122	…
	:	:	:	:	…

7105
7110
7115
7005
7010
7020
7052
7054
7056
7072
7074
7076
7050
7070
7000

Fig. 7

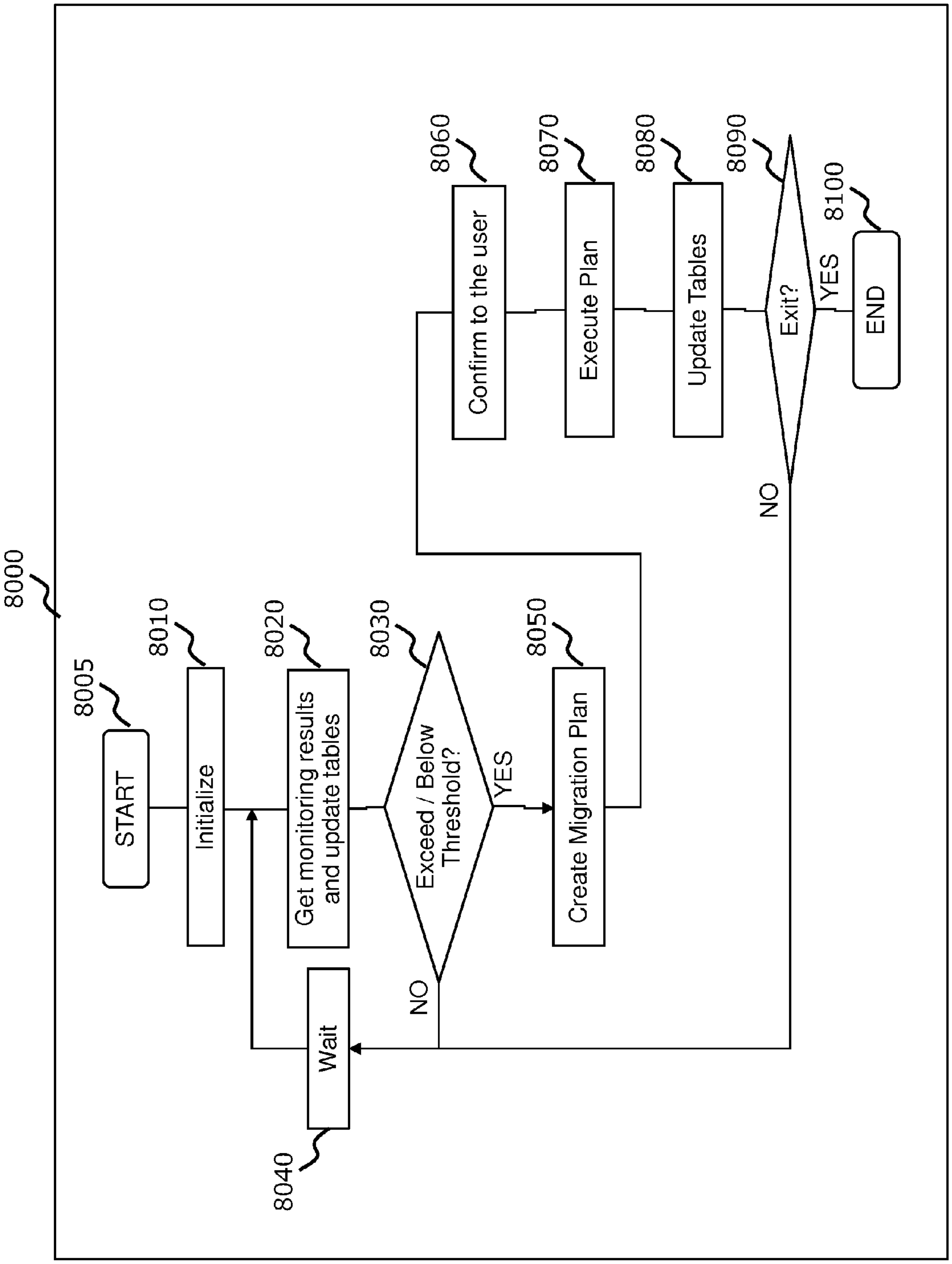

8000
8005
START
8010
Initialize
8020
Get monitoring results and update tables
8030
Exceed / Below Threshold?
YES
NO
8040
Wait
8050
Create Migration Plan
8060
Confirm to the user
8070
Execute Plan
8080
Update Tables
8090
Exit?
YES
NO
8100
END

Fig. 8

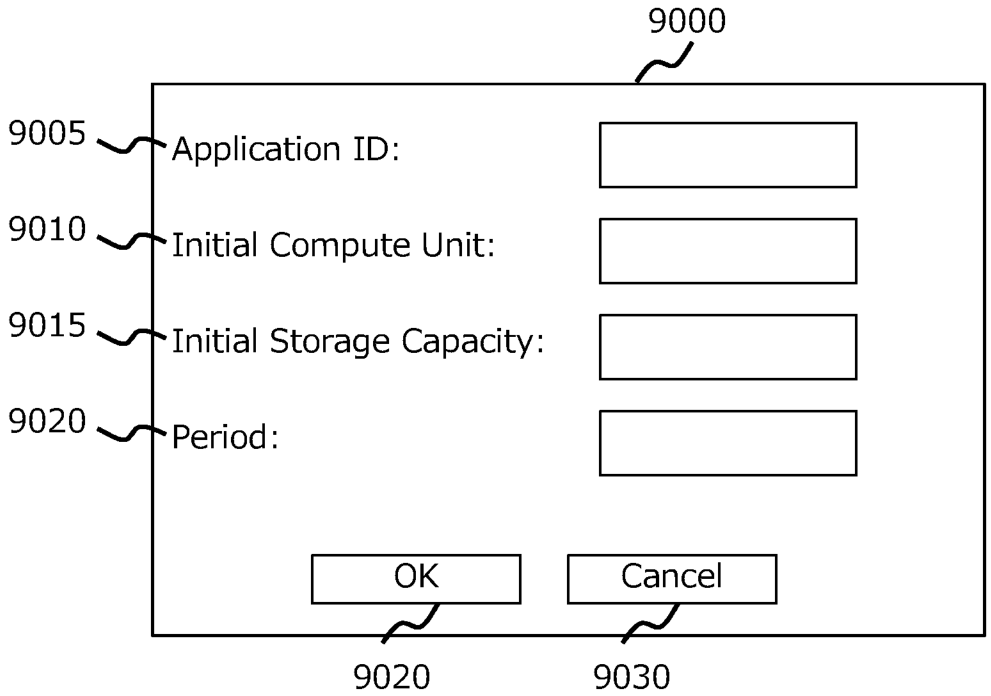
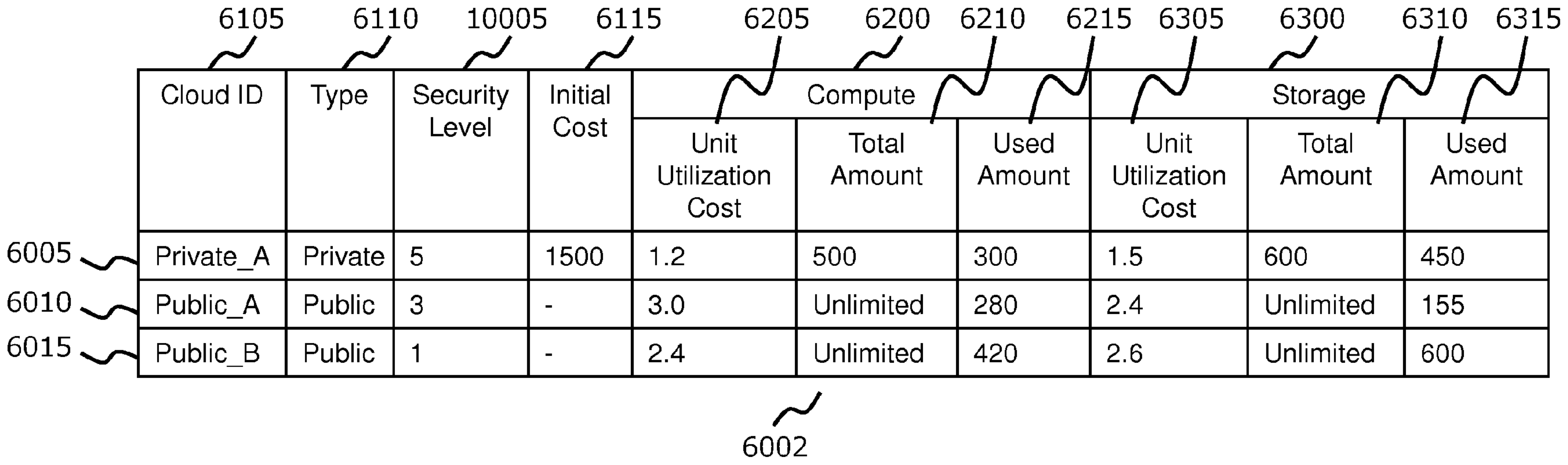

9000
9005
Application ID:
9010
Initial Compute Unit:
9015
Initial Storage Capacity:
9020
Period:
OK
Cancel
9020
9030

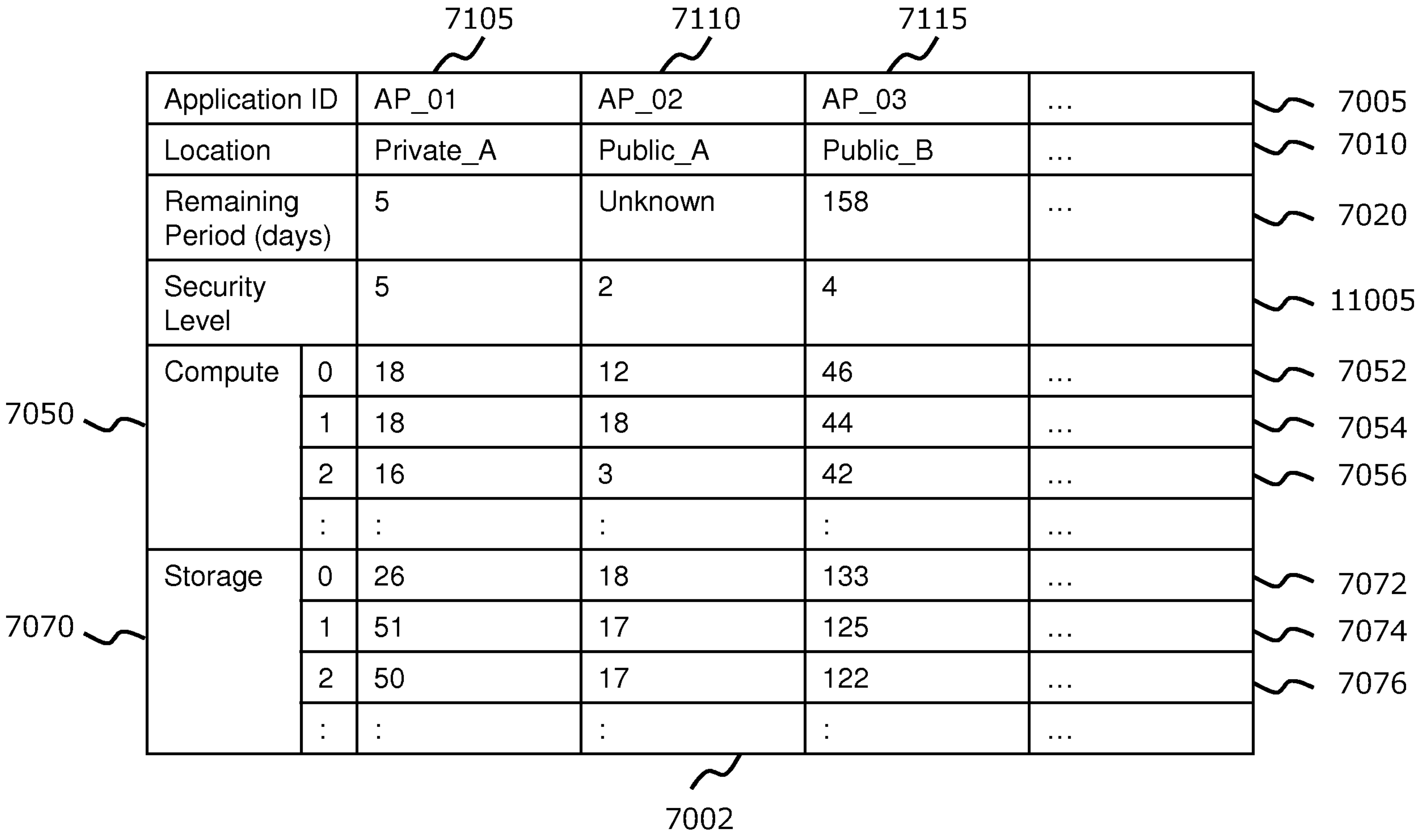
Fig. 9



Cloud ID	Type	Security Level	Initial Cost	Compute			Storage		
				Unit Utilization Cost	Total Amount	Used Amount	Unit Utilization Cost	Total Amount	Used Amount
Private_A	Private	5	1500	1.2	500	300	1.5	600	450
Public_A	Public	3	-	3.0	Unlimited	280	2.4	Unlimited	155
Public_B	Public	1	-	2.4	Unlimited	420	2.6	Unlimited	600

6105
6110
10005
6115
6205
6200
6210
6215
6305
6300
6310
6315
6005
6010
6015
6002

Fig. 10



Application ID		AP_01	AP_02	AP_03	...
Location		Private_A	Public_A	Public_B	...
Remaining Period (days)		5	Unknown	158	...
Security Level		5	2	4	
Compute	0	18	12	46	...
	1	18	18	44	...
	2	16	3	42	...
	:	:	:	:	...
Storage	0	26	18	133	...
	1	51	17	125	...
	2	50	17	122	...
	:	:	:	:	...

7105
7110
7115
7005
7010
7020
11005
7052
7054
7056
7072
7074
7076
7050
7070
7002

Fig. 11

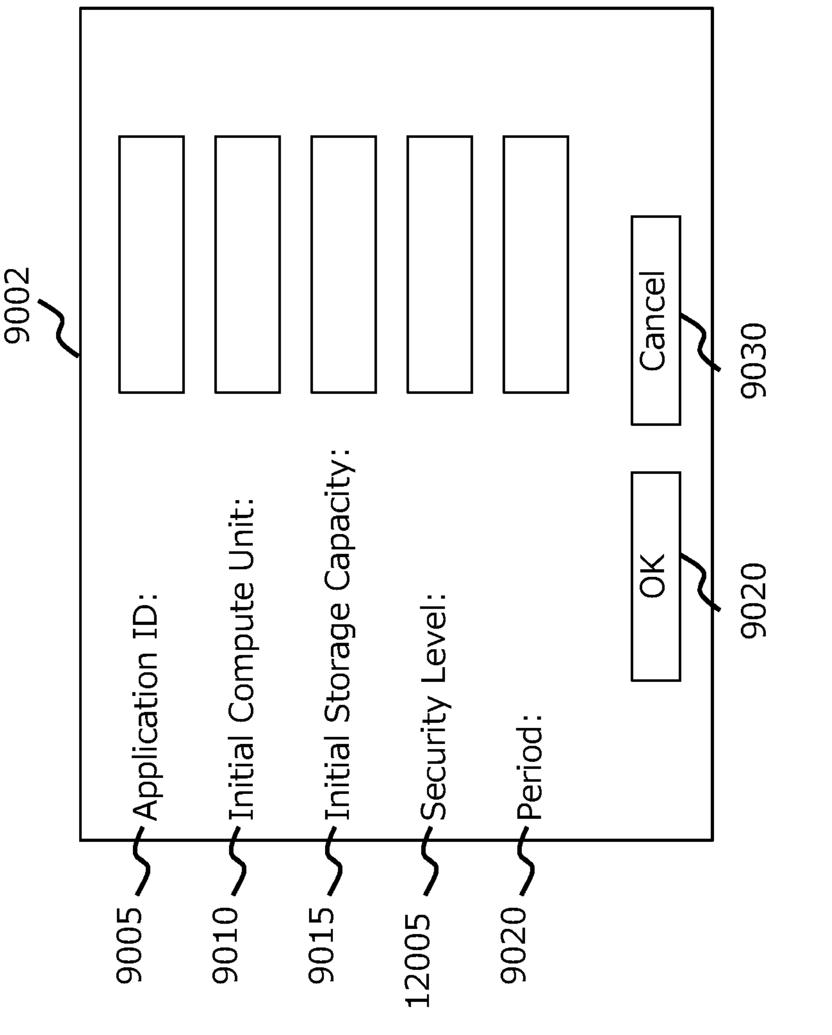

9002
Application ID:
Initial Compute Unit:
Initial Storage Capacity:
Security Level:
Period:
9005
9010
9015
12005
9020
OK
Cancel
9020
9030

Fig. 12

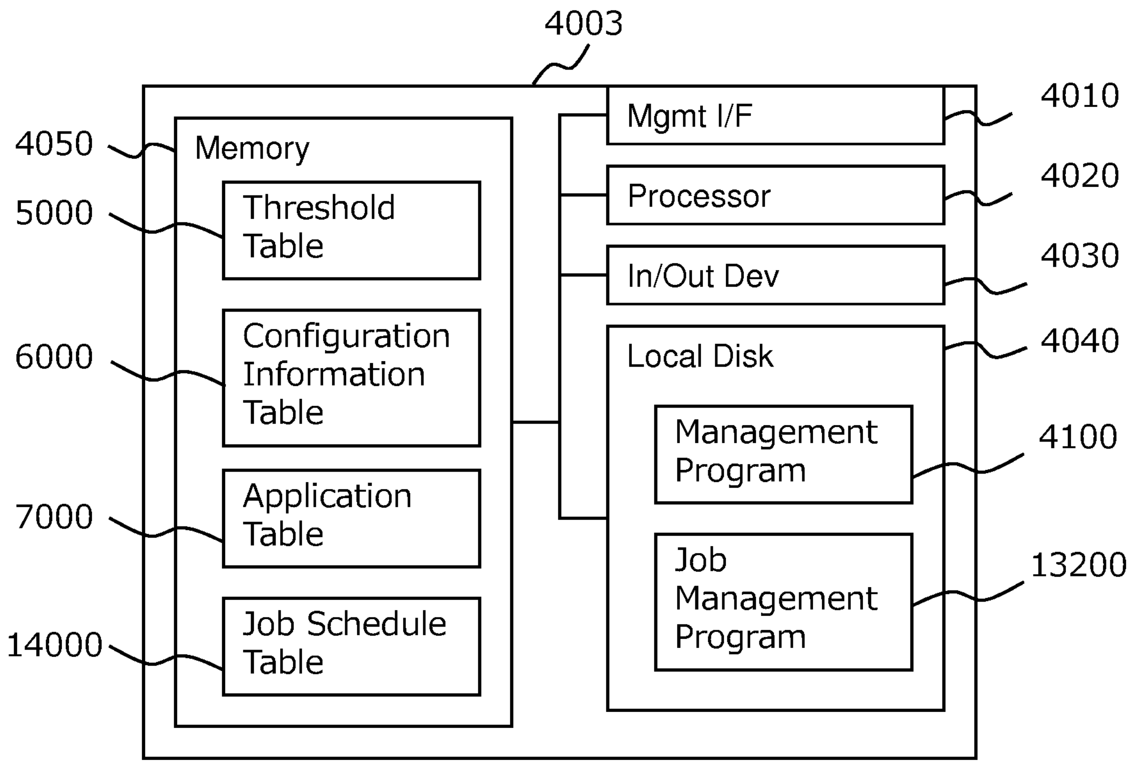
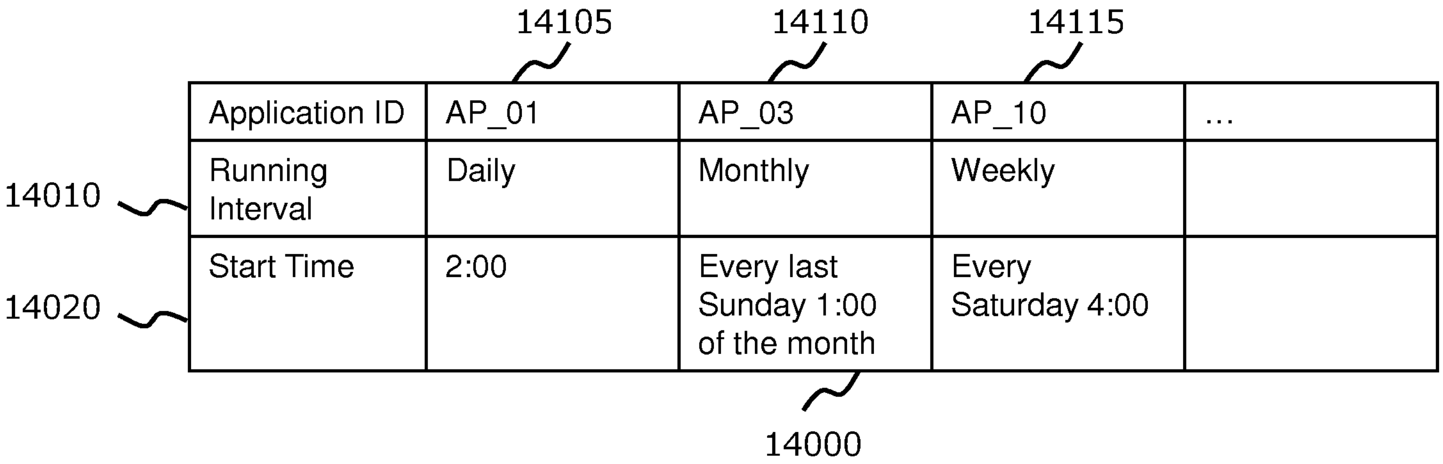

4003
4050
Memory
5000
Threshold Table
6000
Configuration Information Table
7000
Application Table
14000
Job Schedule Table
Mgmt I/F
4010
Processor
4020
In/Out Dev
4030
Local Disk
4040
Management Program
4100
Job Management Program
13200

Fig. 13


14105
14110
14115
14010
14020
14000

Application ID	AP_01	AP_03	AP_10	…
Running Interval	Daily	Monthly	Weekly	
Start Time	2:00	Every last Sunday 1:00 of the month	Every Saturday 4:00	

Fig. 14

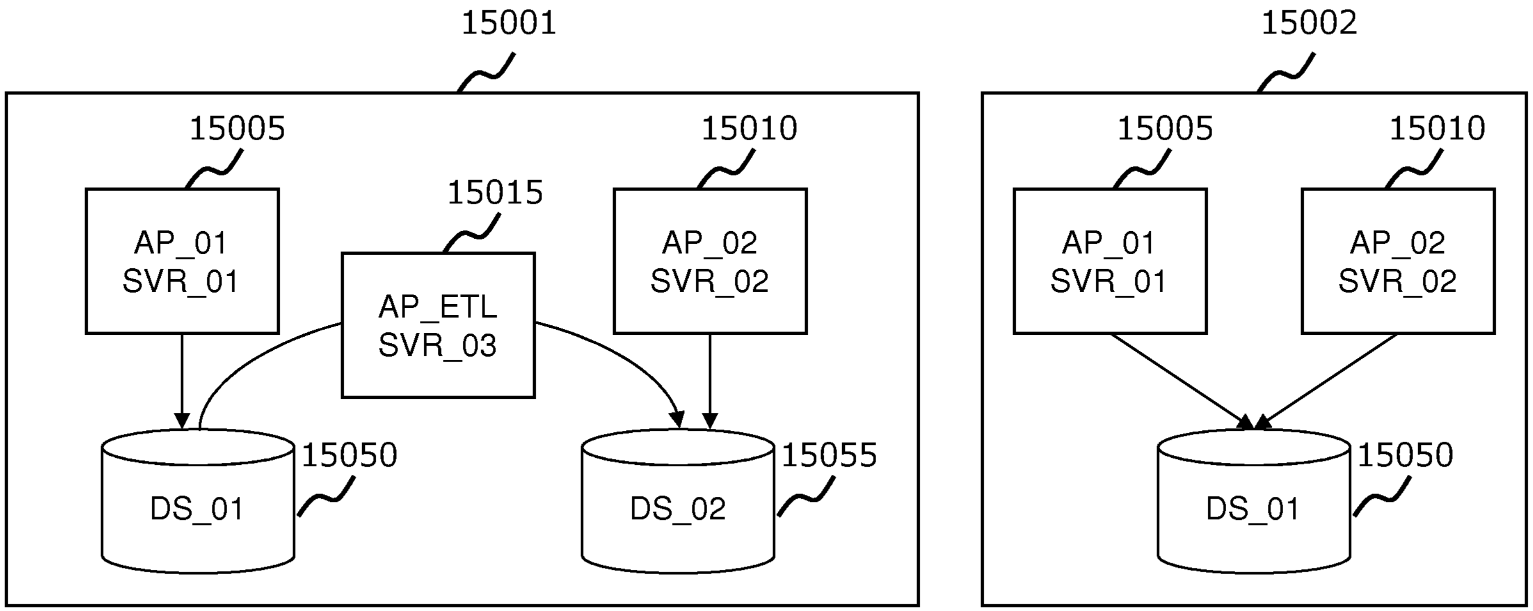
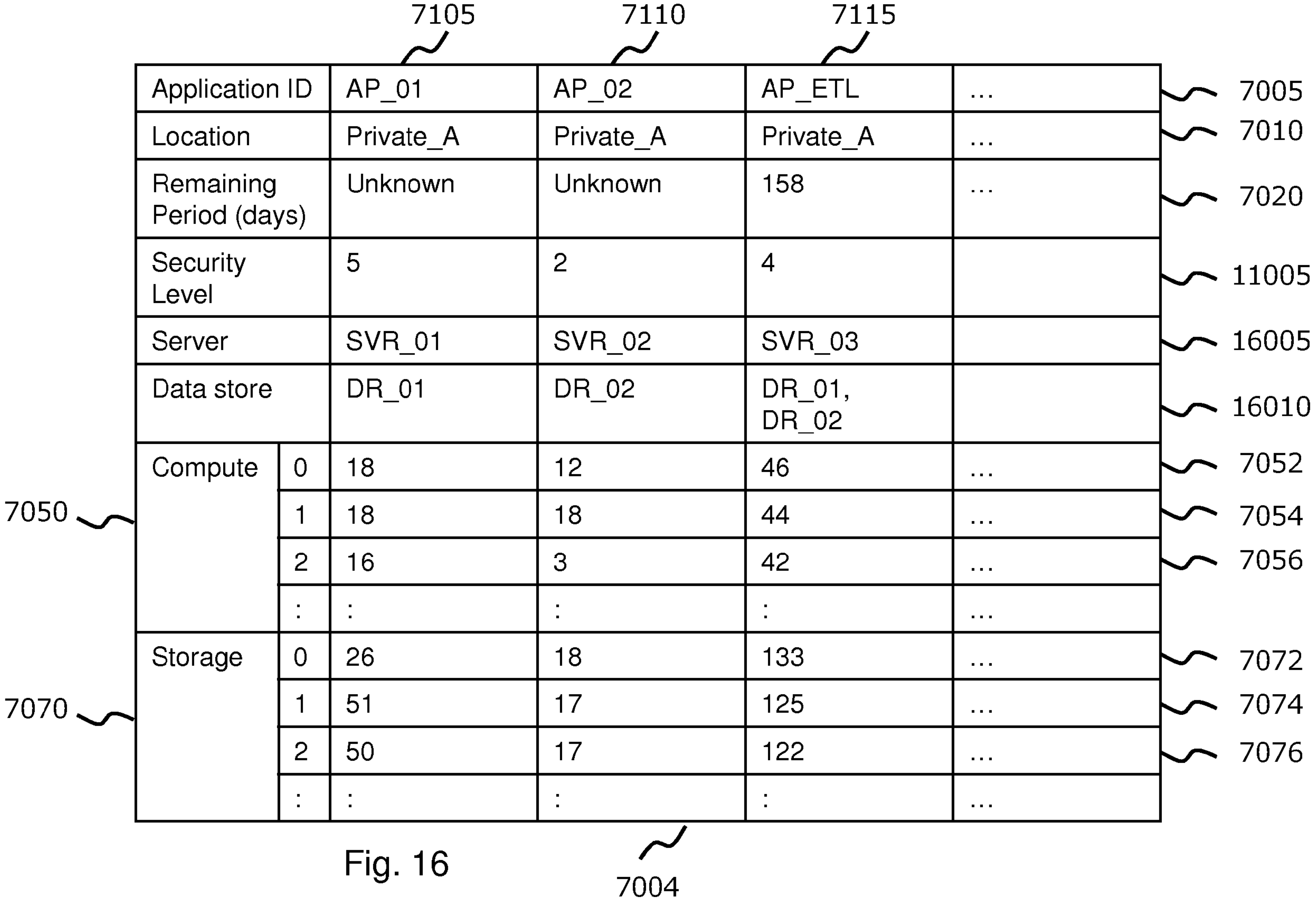

15001
15005
AP_01
SVR_01
15015
AP_ETL
SVR_03
15010
AP_02
SVR_02
DS_01
15050
DS_02
15055
15002
15005
AP_01
SVR_01
15010
AP_02
SVR_02
DS_01
15050

Fig. 15


7105
7110
7115
7005
7010
7020
11005
16005
16010
7052
7054
7056
7072
7074
7076
7050
7070
7004

Application ID		AP_01	AP_02	AP_ETL	…
Location		Private_A	Private_A	Private_A	…
Remaining Period (days)		Unknown	Unknown	158	…
Security Level		5	2	4	
Server		SVR_01	SVR_02	SVR_03	
Data store		DR_01	DR_02	DR_01, DR_02	
Compute	0	18	12	46	…
	1	18	18	44	…
	2	16	3	42	…
	:	:	:	:	…
Storage	0	26	18	133	…
	1	51	17	125	…
	2	50	17	122	…
	:	:	:	:	…

Fig. 16

METHOD AND APPARATUS TO MAXIMIZE RETURN ON INVESTMENT IN HYBRID CLOUD ENVIRONMENT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of Ser. No. 13/525,654, filed Jun. 18, 2012, the entire disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates generally to cloud computing and, more particularly, to improving and preferably maximizing the return on investment (ROI) in a hybrid cloud environment.

Cloud computing is widely used. Cloud computing includes computing on public cloud, private cloud, and hybrid cloud. There are several ways to utilize multiple cloud computing environments. One way is to introduce an abstraction layer to integrate the management points of multiple clouds. One stop portal is provided on this abstraction layer. As a result, the user does not need to use multiple clouds properly. Another way involves migration of workload among multiple clouds. When a workload exceeds the threshold in one cloud, the workload is migrated to another cloud. This function maintains the SLA (Service Level Agreement) of each workload.

There are problems with the current approaches of utilizing multiple cloud computing environments. In the near future, most of the enterprises may utilize both public cloud and private cloud. From the enterprise perspective, the cost structure between private cloud and public cloud is different. Private cloud is owned as assets by the enterprise. Public cloud is used as a pay-as-you-go resource. To maximize the ROI (Return on Investment), the enterprise should recognize these differences in its utilization of private and public clouds.

The current approaches do not provide a standpoint on how an enterprise can maximize the ROI for IT investment in utilizing hybrid clouds. For example, US2011/0231899 discloses systems and methods for one or more cloud computing abstraction layers. The user can plan cloud-computing services, build a cloud-computing service, publish the cloud-computing service for consumption by users, or run the cloud-computing service. Access to disparate public or private cloud-computing resources is through a common interface. Although the reference relates to multiple clouds, it does not distinguish between public cloud and private cloud and does not provide a way to maximize the ROI.

US2011/0145439 provides technology neutral process integration (Cloud Resource Planning), and optimization methodology leveraging a business meta-schema format Cloud Data Interchange (CDI) to integrate, enable, and invoke Cloud services. It provides an abstraction or resource planning layer. The customer does not have to have knowledge or choose different Cloud types and/or understand or choose each underlying service. As such, it provides a one stop portal. Again, although the reference relates to multiple clouds, it does not distinguish between public cloud and private cloud and does not provide a way to maximize the ROI.

US2011/0145413 and U.S. Pat. No. 8,037,187 provide a solution for resource sharing within a cloud-computing environment. One objective is to better utilize idle public or private Cloud infrastructures and improve the availability of Cloud services by allowing different Cloud service providers to virtually combine their services and infrastructures. In the event that there is not enough capacity for a single Cloud service provider to manage its workload, the workload may be shifted to additional infrastructures within the Cloud. Although the reference relates to multiple clouds, it does not distinguish between public cloud and private cloud and does not provide a way to maximize the ROI.

US2011/0145392 provides a solution for enabling the dynamic provisioning (migration) of Cloud-based jobs and resources. Each movement scenario is assigned a specific technique based on rules, profiles, SLA, and/or other such criteria and agreements. Such dynamic adjustments may be especially advantageous in order to balance real-time workload to avoid over-provisioning, to manage Cloud performance, to attain a more efficient or cost-effective execution environment, to off-load a Cloud or specific Cloud resources for maintenance/service, and the like. Coupled devices appear to end-users as a single pool of resources. Again, although the reference relates to multiple clouds, it does not distinguish between public cloud and private cloud and does not provide a way to maximize the ROI.

US2011/0016214 relates to brokering service for computer resources. The brokering services system can aggregate resources for multiple cloud service providers and act as an advocate for or a guarantor of the SLA associated with the workload. A method of providing a brokering for compute resources includes identifying resource capabilities (configuration), receiving a request for compute resources and selecting compute resources, and monitoring workload. The reference does not distinguish between public cloud and private cloud.

BRIEF SUMMARY OF THE INVENTION

Exemplary embodiments of the invention provide a technique to improve and preferably maximize the ROI for IT investment in a hybrid cloud environment composed of private cloud and public cloud. A management program executes the following procedure to maximize the ROI for IT investment when an enterprise utilizes a hybrid cloud environment composed of private cloud(s) and public cloud(s). When the resource utilization ratio of a private cloud exceeds a threshold, more dynamic applications are migrated to the public cloud. "More dynamic" means, for example, an application whose standard deviation of resource utilization is large, an application whose growth ratio of resource utilization is high, or an application whose remaining period is short, when compared with other applications. Otherwise, when the resource utilization ratio of a private cloud falls below the threshold, more stable applications are migrated to the private cloud. "More stable" is the opposite of "more dynamic" for an application when compared with other applications.

In accordance with an aspect of the present invention, a computer comprises: a memory; and a processor being operable to manage two types of clouds, which are private and public clouds, by using information stored in the memory, and to manage a migration of a set of an application and a data between a first type of clouds and a second type of clouds of the two types of clouds, the application running on a server of the first type of clouds, the data to be read or written by the application and being stored in a storage system of the first type of clouds. The processor manages the migration of the set of the application and the data between the first type of clouds and the second type of clouds based on resource utilization of resources including at least one of the server or the storage system.

In some embodiments, the processor is configured to manage the migration using a threshold defined based on at least one of server usage rate or storage usage rate. The processor is configured to migrate the set of the application and the data, from the first type of clouds including one or more private clouds to the second type of clouds including one or more public clouds, if the resource utilization of the private cloud exceeds a first threshold; and the first threshold is defined based on server usage rate and storage usage rate. The processor is configured to migrate the set of the application and the data, from the second type of clouds including one or more public clouds to the second type of clouds including one or more private clouds, if the resource utilization of the private cloud falls below a second threshold; and the second threshold is defined based on server usage rate and storage usage rate. The first threshold is higher than the second threshold.

In specific embodiments, the processor is configured to monitor a plurality of applications on one type of clouds as a migration source for the migration of the set of application and the data. The processor is configured to select for migration from a private cloud to a public cloud, among the plurality of applications, an application which is more dynamic than other applications of the plurality of applications. An application is more dynamic if at least one of the following conditions is met: (i) the application has a standard deviation of resource utilization which is larger than the other applications, (ii) the application has a growth ratio of resource utilization which is higher than the other applications, and (iii) the application has a remaining period which is shorter than the other applications.

In some embodiments, the applications being monitored include one or more batch applications having batch intervals and one or more online applications. The processor is configured to select for migration, from the plurality of applications, an application according to (i) whether the application is a batch application or an online application, (ii) the batch interval if the application is a batch application, and (iii) a type of threshold for migration based on resource utilization of the application including at least one of server usage rate or storage usage rate.

In specific embodiments, the application has a security requirement; and the processor is configured to select a target cloud meeting the security requirement to which to migrate the application. The application is a composite application comprised of multiple applications which access the data; and the processor is configured to migrate the set of the composite application and the data based on resource utilization of resources including at least one of the server or the storage system.

In accordance with another aspect of the invention, a system comprises: a storage system; and a computer including a memory and a processor. The processor is operable to manage two types of clouds, which are private and public clouds, by using information stored in the memory, and to manage a migration of a set of an application and a data between a first type of clouds and a second type of clouds of the two types of clouds, the application running on a server of the first type of clouds, the data to be read or written by the application and being stored in the storage system of the first type of clouds. The processor manages the migration of the set of the application and the data between the first type of clouds and the second type of clouds based on resource utilization of resources including at least one of the server or the storage system.

In some embodiments, the system further comprises the server of the first type of clouds on which the application runs.

Another aspect of this invention is directed to a computer-readable storage medium storing a plurality of instructions for controlling a data processor to manage migration among clouds. The plurality of instructions comprise: instructions that cause the data processor to manage two types of clouds, which are private and public clouds, by using information stored in a memory; and instructions that cause the data processor to manage a migration of a set of an application and a data between a first type of clouds and a second type of clouds of the two types of clouds, the application running on a server of the first type of clouds, the data to be read or written by the application and being stored in a storage system of the first type of clouds. The migration of the set of the application and the data between the first type of clouds and the second type of clouds is managed based on resource utilization of resources including at least one of the server or the storage system.

These and other features and advantages of the present invention will become apparent to those of ordinary skill in the art in view of the following detailed description of the specific embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an example of a Hybrid Cloud Environment according to the first embodiment of the present invention.

FIG. **1**A shows an example of a logical view of the system according to the first embodiment.

FIG. **2** shows an example of the configuration of a Public Cloud according to the first embodiment.

FIG. **3** shows an example of the configuration of a Private Cloud.

FIG. **4** shows an example of the configuration of a Management Server according to the first embodiment.

FIG. **5** shows an example of a Threshold Table in the Management Server of FIG. **4**.

FIG. **6** shows an example of a Configuration Information Table in the Management Server of FIG. **4** according to the first embodiment.

FIG. **7** shows an example of an Application Table in the Management Server of FIG. **4** according to the first embodiment.

FIG. **8** shows an example of a flow diagram illustrating the process of a management program according to the first embodiment.

FIG. **9** shows an example of a self service provisioning GUI in the Management Server of FIG. **4** according to the first embodiment.

FIG. **10** shows an example of a Configuration Information Table according to the second embodiment.

FIG. **11** shows an example of an Application Table according to the second embodiment.

FIG. **12** shows an example of a self service provisioning GUI according to the second embodiment.

FIG. **13** shows an example of the configuration of the Management Server according to the third embodiment.

FIG. **14** shows an example of the Job Schedule Table.

FIG. **15** shows an example of a Logical View of the system according to the fourth embodiment.

FIG. **16** shows an example of the Application Table according to the fourth embodiment.

DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description of the invention, reference is made to the accompanying drawings which form a part of the disclosure, and in which are shown by way of illustration, and not of limitation, exemplary embodiments by which the invention may be practiced. In the drawings, like numerals describe substantially similar components throughout the several views. Further, it should be noted that while the detailed description provides various exemplary embodiments, as described below and as illustrated in the drawings, the present invention is not limited to the embodiments described and illustrated herein, but can extend to other embodiments, as would be known or as would become known to those skilled in the art. Reference in the specification to "one embodiment," "this embodiment," or "these embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention, and the appearances of these phrases in various places in the specification are not necessarily all referring to the same embodiment. Additionally, in the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one of ordinary skill in the art that these specific details may not all be needed to practice the present invention. In other circumstances, well-known structures, materials, circuits, processes and interfaces have not been described in detail, and/or may be illustrated in block diagram form, so as to not unnecessarily obscure the present invention.

Furthermore, some portions of the detailed description that follow are presented in terms of algorithms and symbolic representations of operations within a computer. These algorithmic descriptions and symbolic representations are the means used by those skilled in the data processing arts to most effectively convey the essence of their innovations to others skilled in the art. An algorithm is a series of defined steps leading to a desired end state or result. In the present invention, the steps carried out require physical manipulations of tangible quantities for achieving a tangible result. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals or instructions capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, instructions, or the like. It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise, as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing," "computing," "calculating," "determining," "displaying," or the like, can include the actions and processes of a computer system or other information processing device that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system's memories or registers or other information storage, transmission or display devices.

The present invention also relates to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, or it may include one or more general-purpose computers selectively activated or reconfigured by one or more computer programs. Such computer programs may be stored in a computer-readable storage medium including non-transient medium, such as, but not limited to optical disks, magnetic disks, read-only memories, random access memories, solid state devices and drives, or any other types of media suitable for storing electronic information. The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general-purpose systems may be used with programs and modules in accordance with the teachings herein, or it may prove convenient to construct a more specialized apparatus to perform desired method steps. In addition, the present invention is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein. The instructions of the programming language(s) may be executed by one or more processing devices, e.g., central processing units (CPUs), processors, or controllers.

Exemplary embodiments of the invention, as will be described in greater detail below, provide apparatuses, methods and computer programs for improving and preferably maximizing the return on investment (ROI) in a hybrid cloud environment composed of private cloud and public cloud.

1. Embodiment 1

The first embodiment discloses how the enterprise who owns private clouds maximizes the ROI by using public cloud for peak or unexpected workload which cannot be executed in the private clouds. The basic strategy of this embodiment is to keep a high utilization ratio of private clouds as much as possible. Private clouds are owned by the enterprise, therefore they consumes owned cost regardless of whether private clouds are used. So, the enterprise should keep high utilization ratio of private clouds.

FIG. **1** shows an example of a Hybrid Cloud Environment according to the first embodiment of the present invention. A hybrid cloud **1100** includes public clouds **2000**, private clouds **3000**, and a management server **4000**. FIG. **1** shows three public clouds and three private clouds, but the invention is not limited to these numbers of clouds. The public clouds **2000** and private clouds **3000** are connected via a Data Network **1030**. This network is typically a WAN (Wide Area Network), but the invention is not limited to this. The public clouds **2000**, private clouds **3000**, and management server **4000** are connected via a management network **1020**. This network is typically a WAN, but the invention is not limited to this. In the embodiment shown, the management network and data network are separate, but the invention is not limited to this. In addition, the management server **4000** and each cloud are separate, but the invention is not limited to this. For example, the management server can be located in one of the private clouds.

FIG. **1**A shows an example of a logical view of the system according to the first embodiment. In the system **1501**, each application uses a corresponding data store. In this environment, application AP_**01** creates and stores data to data store DS_**01** and application AP_**02** creates and stores data to data store DS_**02**. Application AP**01** is executed on server SVR_**01 1505** and Application AP_**02** is executed on server SVR_**02 1510**. Server is not limited to physical server. Virtual server may be used. Data store is not limited to DAS (Direct Attached Storage), NAS (Network Attached Storage), and SAN (Storage Area Network). Any kind of data store can be used. The application and the corresponding data store are on the same type of clouds. For example, they may be on the same private cloud or on different private clouds, and they may be migrated to the same public cloud or to different public clouds.

FIG. **2** shows an example of the configuration of a Public Cloud according to the first embodiment. The public cloud

2000 includes servers **2010** and storage subsystems **2030** which are connected via an internal data network **2070**. This network is typically a SAN, but the invention is not limited to this. The servers **2010** and storage subsystems **2030** are connected via an internal management network **2050**. This network is typically a LAN (Local Area Network), but the invention is not limited to this. FIG. **2** shows three servers **2010** and three storage subsystems **2030**, but the invention is not limited to these numbers. The servers **2010** and storage subsystems **2030** are separate in FIG. **2**, but the invention is not limited to this. For example, the servers **2010** can have DAS and the storage subsystems **2030** can be eliminated.

FIG. **3** shows an example of the configuration of a Private Cloud. The Private cloud **3000** includes servers **3010** and storage subsystems **3030**, which are connected via an internal data network **3070**. This network is typically a SAN (Storage Area Network), but the invention is not limited to this. The servers **3010** and storage subsystems **3030** are connected via an internal management network **3050**. This network is typically a LAN (Local Area Network), but the invention is not limited to this. FIG. **3** shows three servers **3010** and three storage subsystems **3030**, but the invention is not limited to these numbers. The servers **3010** and storage subsystems **3030** are separate, but the invention is not limited to this. For example, the servers **3010** can have DAS (Direct Attached Storage) and the storage subsystems **3030** can be eliminated.

FIG. **4** shows an example of the configuration of a Management Server according to the first embodiment. This figure shows the management server **4000** which exists in the hybrid cloud environment **1100** of FIG. **1**. The management server **4000** includes a management interface **4010**, a processor **4020**, an input/output device **4030**, a local disk **4040**, and a memory **4050**. The Management Interface **4010** is an interface to the Management Network **1020** of FIG. **1**. The Input/Output Device **4030** is a user interface such as monitor, keyboard, and/or mouse. The Local Disk **4040** contains a Management Program **4100**. The Management Program **4100** is loaded to the Memory **4050** and executed by the Processor **4020**. The procedure of the Management Program **4100** is disclosed later using FIG. **8**. The Memory **4050** contains a threshold table **5000**, a configuration information table **6000** and an application table **7000**. Each table is described later.

FIG. **5** shows an example of a Threshold Table in the Management Server **4000** of FIG. **4**. In the threshold table **5000**, each column shows the upper threshold and bottom threshold of a resource. Row **5005** defines the upper threshold, row **5010** defines the bottom threshold, and row **5015** defines the target ratio. Column **5110** shows the threshold of the compute resource. The upper threshold is 80%, the bottom threshold is 70%, and the target ratio is 75%. Column 5120 shows the threshold of the storage resource. The upper threshold is 85%, the bottom threshold is 75%, and the target ratio is 80%. These values represent one example and do not limit the invention. In the example shown, the threshold of the compute and the threshold of the storage are different, but it is possible to set the same threshold.

FIG. **6** shows an example of a Configuration Information Table in the Management Server **4000** of FIG. **4** according to the first embodiment. In the configuration information table **6000**, column **6105** shows the identification of the cloud. Column **6110** shows the type of the cloud, which is public or private. Column **6115** shows the initial cost of the cloud. The initial cost of a public cloud is typically 0. Column **6200** shows the compute resource information of the cloud. It has three columns **6205**, **6210**, and **6215**. Column **6205** shows the unit utilization cost of the compute resource. Column **6210** shows the total amount of the compute resource. Column **6215** shows the used amount of the compute resource. Column **6300** shows the storage resource information of the cloud. It has three columns **6305**, **6310**, and **6315**. Column **6305** shows the unit utilization cost of the storage resource. Column **6310** shows the total amount of the storage resource. Column **6315** shows the used amount of the storage resource.

Each row shows configuration information of a cloud. For example, row **6005** shows the configuration information of cloud Private_A . This is a private cloud and the initial cost is 1500. The unit utilization cost of this compute resource is 1.2. The total compute amount is 500 and 300 is already used. The unit utilization cost of this storage resource is 1.5. The total storage amount is 600 and 450 is already used. Usually, the resource amount of the public cloud is unlimited for the user perspective. Therefore, the total amount of each resource of the public cloud is unlimited.

FIG. **7** shows an example of an Application Table in the Management Server **4000** of FIG. **4** according to the first embodiment. The application table **7000** shows the application information and history of resource consumption of the application. Row **7005** shows the identification of the application. Row **7010** shows the location of the application. This shows the identification of the cloud in which the application is deployed. Row **7020** shows the remaining days of the application. If the remaining days become 0, this application will be undeployed. For some applications, the remaining period can be set in advance and the valid remaining period is set in this field. For other applications, the remaining period cannot be set in advance and the remaining period is "Unknown."

Rows **7050** (**7052**, **7054**, **7056**, etc.) show the history of compute resource consumption. Row **7052** shows the latest compute resource consumption. Row **7054** shows the second latest compute resource consumption. Row **7054** shows the third latest compute resource consumption. In this embodiment, Rows **7050** have 30 histories of compute resource consumption, but the invention is not limited to this number. Rows **7070** (**7072**, **7074**, **7076**, etc.) show the history of storage resource consumption. Row **7072** shows the latest storage resource consumption. Row **7074** shows the second latest storage resource consumption. Row **7074** shows the third latest storage resource consumption. In this embodiment, Rows **7070** have 30 histories of storage resource consumption, but the invention is not limited to this number.

Each column (**7105**, **7110**, **7115**, etc.) shows application information. For example, column **7105** shows the information of an application AP_**01**. This application is deployed on the cloud Private_A. The remaining period of this application is 5 days. The latest compute resource consumption is 18 and the storage resource consumption is 26.

FIG. **8** shows an example of a flow diagram illustrating the process of a management program **8000** according to the first embodiment, which is the management program **4100** in the management server **4000** of FIG. **4**. The program starts at step **8005**. In step **8010**, when the management program **4100** is loaded from the local disk **4040** to the memory **4050**, the threshold table **5000**, configuration Information table **6000**, and application table **7000** are created in the memory **4050**. For the threshold table, the default (preset) value can be used for the threshold table or the user can set each threshold. For the configuration information table, information of the configuration information table is acquired from each cloud. For this, an agent can be placed in each cloud or the management server **4100** can use API if a cloud provides API for this purpose. For the application table, information of the application table is acquired from each application. For this, an agent can be placed in each cloud or the management server **4100** can use API if each application provides API for this purpose.

In step **8020**, the program gets monitoring results from each cloud and application and updates the tables. For the configuration information table, the program updates the used amount column of compute and storage in each cloud. For the application table: (1) if an application is undeployed, the corresponding application column is deleted; (2) the program updates the Remaining Period row if required; and (3) the program updates histories of compute and storage resource consumption of each application.

In step **8030**, the program checks whether a private cloud whose resource utilization exceeds its threshold exists. If yes, the program goes to step **8050**; if no, the program proceeds to step **8040**. In step **8040**, the program waits for a while and then goes to step **8020**.

In step **8050**, the program creates a migration plan. The basic strategy of this embodiment is to keep a high utilization ratio of private clouds as much as possible. How to create a plan depends on the threshold type, but the basic procedure is described as follows. In step **8050**-(**1**), the program decides the application sets for a candidate. If the resource utilization of the private cloud exceeds the upper threshold, the application sets for candidate are applications executed on the private cloud. If the resource utilization of the private cloud falls below the bottom threshold, the application sets for candidate are applications executed on the public clouds. In step **8050**-(**2**), the program calculates the evaluated value of each application. In step **8050**-(**3**), the program sorts applications in descending order based on the evaluated value. In step **8050**-(**4**), the program selects applications from the beginning until the utilization ratio of the private cloud exceeds or falls below the target ratio. In this example, the target ratio to exceed and the target ratio to fall below are the same, but the invention is not limited to this. It is possible to set different target ratios to exceed and fall below. Step **8050**-(**2**) depends of the type of the threshold, as illustrated in the three cases below.

In the first case where the compute resource utilization exceeds the upper threshold, the evaluated value e_i for each application c_i is calculated as follows:

$$e_i = \frac{c_{ip_a}^{p}}{c_{ip_a}^{d}} \times \alpha_1 + \sigma(c_{ip_a}^{p}) \times \beta_1$$

where,

$c_{ip_a}^{P}$ is a maximum compute resource utilization of an application c_i among period p_a,

$c_{ip_a}^{d}$ is a maximum storage resource utilization of an application c_i among period p_a,

$\sigma(c_{ip_a}^{P})$ is a standard deviation of compute resource utilization of an application

c_i among period p_a,

α_2 and β_2 are arbitrary constant values, and

period p_a is an arbitrary period below that stored in the application table **7000**. In this example, the period is 30 histories, but the invention is not limited to this number.

In the second case where the storage resource utilization exceeds the upper threshold, the evaluated value e_i for each application c_i is calculated as follows:

$$e_i = c_{ip_a}^{dgr} \times \alpha_2 + \sigma(c_{ip_a}^{P}) \times \beta_2$$

where,

$c_{ip_b}^{dgr}$ is a storage resource growth rate of an application c_i among period p_b,

$\sigma(c_{ip_b}^{P})$ is a standard deviation of compute resource utilization of an application c_i among period p_b,

α_2 and β_2 are arbitrary constant values, and

period p_b is an arbitrary period below that stored in the application table **7000**.

In this example, this period is 30 histories, but the invention is not limited to this number.

In the third case where the compute resource utilization or storage resource utilization falls below the bottom threshold, the evaluated value e_i for each application c_i is calculated as follows:

$$e_i = \frac{1}{c_{ip_c}^{dgr}} \times \alpha_3 + \frac{1}{\sigma(c_{ip_c}^{p})} \times \beta_3 + \frac{1}{c_i^{tr}} \times \gamma_3$$

where,

$c_{ip_c}^{dgr}$ is a storage resource growth rate of an application c_i among period p_a,

$\sigma(c_{ip_c}^{P})$ is a standard deviation of compute resource utilization of an application c_i among period p_a,

c_i^{cr} is a remaining period of an application c_i,

α_3, β_3 and γ_3 are arbitrary constant values, and

period p_c is an arbitrary period below that stored in the application table **7000**.

In this example, this period is 30 histories, but the invention is not limited to this number.

In step **8060**, the program provides the created plan to the user. The user can select immediate execution or scheduled execution. If scheduled execution is specified, the program registers the plan to the scheduler. In step **8070**, the program executes the created plan. In step **8080**, the configuration will change based on the migration. Therefore, the configuration information table **6000** and application table **7000** are updated. In step **8090**, the program checks whether there is termination indication by the user. If termination indication exists, the program goes to step **8100**; otherwise, it goes to step **8040**. The process ends at step **8100**.

FIG. **9** shows an example of a self service provisioning GUI **9000** in the Management Server **4000** of FIG. **4** according to the first embodiment. This GUI is used when a user wants to provision IT resources. The user inputs an identification of an application into the Application ID field **9005**, initial compute unit into the Initial Compute Unit field **9010**, and initial storage capacity into the Initial Storage Capacity field **9015**. Additionally, if the user can specify the period at this time, he/she inputs the period of use into the Period field **9020**. If the Cancel button **9030** is pressed, the provisioning process is canceled. If the OK button is pressed, the management program **4100** executes the following procedure.

First, the management program **4100** decides the provisioning target. If the utilization ratio of the private cloud is below bottom threshold, provisioning target is private cloud. Otherwise, provisioning target is public cloud. If there are multiple public clouds, the program selects the cheapest cloud for the provisioning workload. Second, the management program provisions IT resources from the selected cloud. Third, the management program adds a new column to the application table **7000**. The identification of the application is set to the Application ID **7005** and the identification of the provisioned cloud is set to the Location field **7010**. If the period is specified, specified period is set to the Period field **7020**. Otherwise, Unknown is set. Also, target cloud of the provisioning can be specified by the user. If the private cloud is specified and the resource utilization of the private cloud exceeds the upper threshold, an error message is displayed.

In this embodiment, an enterprise can maximize the ROI for IT investment when utilizing a hybrid cloud environment composed of private cloud and private cloud by executing following procedure. When the resource utilization ratio of the private cloud exceeds the threshold, more dynamic applications are migrated to the public cloud. "More dynamic" means, for example, an application whose standard deviation of resource utilization is large, an application whose growth ratio of resource utilization is high, and an application whose remaining period is short. Otherwise, when the resource utilization ratio of the private cloud falls below the threshold, more stable applications are migrated to the private cloud.

2. Embodiment 2

In some cases, an application has security requirements. As such, the application has to be executed on the cloud that satisfies the security requirements. In the second embodiment, the method to satisfy security requirements is disclosed. The procedure of the second embodiment is almost the same as that of the first embodiment. Therefore, only the differences are described. The system configuration is same as that for the first embodiment (FIGS. **1**-**3**).

FIG. **10** shows an example of a Configuration Information Table according to the second embodiment. This configuration information table **6002** differs from the configuration information table **6000** of the first embodiment shown in FIG. **6** in that it has an additional Security Level column **10005**. This column shows the security level of the cloud. For example, the security level of the Private_A cloud is 5. In this example, the security level is defined with five steps from 1 to 5, but the invention is not limited to this.

FIG. **11** shows an example of an Application Table according to the second embodiment. This application table **7002** differs from the application table **7000** of the first embodiment shown in FIG. **7** in that it has an additional Security level row **11005**. This row shows the security level of the application. For example, the security level of the AP_**03** application is 4. In this example, the security level is defined with five steps from 1 to 5, but the invention is not limited to this.

The flow diagram of the process of the management server is almost same as that of the first embodiment shown in FIG. **8**, but the following step is different. In step **8050**-(**4**), the program selects applications from the beginning until the utilization ratio of private cloud exceeds or falls below the target ratio, as in the first embodiment. However, if the security level of the selected application is higher than the security level of the target cloud, this application is eliminated.

FIG. **12** shows an example of a self service provisioning GUI according to the second embodiment. This self service provisioning GUI **9002** of the management server **4000** differs from the self service provisioning GUI **9000** of the first embodiment shown in FIG. **9** in that it has an additional "Security Level' field **12005**. The user inputs a security level of the application into this field and this value is set to the security level row **11005** of the application table **7002**. When the management program decides the provisioning target, a cloud whose security level is higher than the security level of the application can be the target.

In the second embodiment, an enterprise can maximize the ROI for IT investment when utilizing a hybrid cloud environment composed of private cloud and private cloud even if the application has a security level.

3. Embodiment 3

Applications are divided into two types. One is an online application which is executed steadily and the other is a batch application which is executed on a periodic basis. The third embodiment is directed to a method to address application types. The procedure of the third embodiment is almost the same as that of the first embodiment. Therefore, only the differences are described. The system configuration is same as that of the first embodiment (FIGS. **1**-**3**).

FIG. **13** shows an example of the configuration of the Management Server according to the third embodiment. This management server **4003** in the hybrid cloud environment **1100** differs from the management server **4000** of the first embodiment shown in FIG. **4** in that it includes a Job Management Program **13200** and a Job Schedule Table **14000**. The Job Management Program **13200** manages the Job Schedule Table **14000**. It means to create, modify, and delete the table, and to execute applications based on the table. Job Schedule Table **14000** is disclosed later using FIG. **14**.

FIG. **14** shows an example of the Job Schedule Table **14000**. This table shows the job execution schedule for each batch application. Row **14010** shows the running interval of the batch job. In this example, the value of this field is one of Daily, Weekly, or Monthly, but the invention is not limited to this. Row **14020** shows the start time of the batch application. Each column (**14105**, **14110**, **14115**, etc.) shows the batch application information. For example, column **14105** shows the information of batch application AP_**01**. This application is executed at 2:00 every day.

The flow diagram of the process of the management server is almost the same as that of the first embodiment shown in FIG. **8**. The following step is different. Step **8050**-(**2**) is divided into the following two steps. In step **8050**-(**2-1**), the program decides the batch evaluate value $b_{c_i}^{j}$ for each application c_i. If an application c_i is not a batch application, this value is $b_{c_i}^{2}$. If an application c_i is a batch application and the interval is daily, this value is $b_{c_i}^{2}$. If an application c_i is a batch application and the interval is weekly, this value is $b_{c_i}^{2}$. If an application c_i is a batch application and the interval is monthly, this value is b_{c}^{2}. Here, $b_{c_i}^{2}<b_{c_i}^{2}<b_{c_i}^{2}<b_{c_i}^{4}$. Step **8050**-(**2-2**) depends on the type of the threshold as described below.

In the first case where the compute resource utilization exceeds the upper threshold, the evaluated value e_i for each application c_i is calculated as follows:

$$e_i = \frac{c_{ip_a}^{p}}{c_{ip_a}^{d}} \times \alpha_1 + \sigma(c_{ip_a}^{p}) \times \beta_1 + b_{c_i}^{j}$$

where,

$c_{ip_a}^{p}$ is a maximum compute resource utilization of an application c_i among period p_a,

$c_{ip_a}^{d}$ is a maximum storage resource utilization of an application c_i among period p_a,

$\sigma(c_{ip_a}^{p})$ is a standard deviation of compute resource utilization of an application c_i among period p_a,

$b_{c_i}^{j}$ is a batch evaluate value of an application c_i,

α_i and β_i are arbitrary constant values, and
period p_a is an arbitrary period below that stored in the application table **7000**.

In this example, this period is 30 histories, but the invention is not limited to this number.

In the second case where the storage resource utilization exceeds the upper threshold, the evaluated value e_i for each application c_i is calculated as follows:

$$e_i = c_{ip_a}{}^{d_{gr}} \times \alpha_2 + \sigma(c_{ip_a}{}^{P}) \times \beta_2 + b_{e_i}{}^{j}$$

where,
$c_{ip_b}{}^{d_{gr}}$ is a storage resource growth rate of an application c_i among period p_b,
$\sigma(c_{ip_b}{}^{P})$ is a standard deviation of compute resource utilization of an application c_i among period p_b,
$b_{c_i}{}^{j}$ is a batch evaluate value of an application c_i,
α_2 and β_2 are arbitrary constant values, and
period p_b is an arbitrary period below that stored in application table **7000**. In this example, this period is 30 histories, but the invention is not limited to this number.

In the third case where the compute resource utilization or storage resource utilization falls below the bottom threshold, the evaluated value e_i for each application c_i is calculated as follows:

$$e_i = \frac{1}{c_{ip_c}^{d_{gr}}} \times \alpha_2 + \frac{1}{\sigma(c_{ip_c}^{p})} \times \beta_2 + \frac{1}{c_i^{t_r}} \times \gamma_3 + \frac{1}{b_{c_i}^{j}}$$

where,
$c_{ip_a}{}^{d_{gr}}$ is a storage resource growth rate of an application c_i among period p_a,
$\sigma(c_{p_a}{}^{P})$ is a standard deviation of compute resource utilization of an application among period p_a,
$c_i{}^{t_r}$ is a remaining period of an application c_i,
$b_{c_i}{}^{j}$ is a batch evaluate value of an application c_i,
α_2, β_2, and γ_2 are arbitrary constant values, and
period p_c is an arbitrary period below that stored in the application table **7000**.

In this example, this period is 30 histories, but the invention is not limited to this number.

The longer interval of an application means the longer the idle time. Therefore, those applications should be executed in a public cloud whose accounting model is pay-as-you-go.

In this embodiment, an enterprise can maximize the ROI for IT investment when utilizing a hybrid cloud environment composed of private cloud and private cloud even if the batch applications and online applications are executed.

4. Embodiment 4

In some cases, a composite application is used. A composite application is an application built by combining multiple existing applications. There are multiple forms of the composite application. For example, an online application AP_**01** creates and stores data to data store DS_**01** and a batch application AP_**02** analyzes it periodically.

FIG. **15** shows an example of a Logical View of the system according to the fourth embodiment. This figure shows the logical view of the system **15001** and system **15002**. Two patterns should be considered as a composite application.

The logical view **15001** shows that one application uses multiple data stores. In this environment, online application AP_**01** creates and stores data to data store DS_**01**. Then, ETL (Extract/Transform/Load) application AP_ETL reads data from data store DS _**01** and writes data to data store DS_**02**. Finally, batch application AP_**02** analyzes it periodically using data store DS_**02**. Application AP_**01** is executed on server SVR_**01 1005**, Application AP_**02** is executed on server SVR_**02 15010**, and Application AP_ETL is executed on server SVR_**03 15015**. Server is not limited to physical server. Virtual server may be used. Data store is not limited to DAS, NAS, and SAN. Any kind of data store can be used.

The logical view **15002** shows that multiple applications share one data store. In this environment, online application AP_**01** creates and stores data to data store DS_**01**, and batch application AP_**02** analyzes periodically using data store DS_**01**.

FIG. **16** shows an example of the Application Table according to the fourth embodiment. This application table **7004** differs from the application table **7002** of the second embodiment shown in FIG. **11** in that it includes additional server row **16005** and data store row **16010**. Server row **16005** shows the server identification in which the application is deployed. Data store row **16010** shows the data store identification(s) that the application uses.

The flow diagram of the process of the management server is almost same as that of the second embodiment, but the following steps are different. In step **8010**, the management program **4100** acquires server identification and data store identification of each application from each cloud and each application. Then the information is added to the application table **7004**. In step **8020**, if update such as migration occurs, the management program **4100** updates the application table **7004** including server row **16005** and data store row **16010**. In step **8050**, the program treats the composite application as one application. If the applications share one data store, such applications are treated as one application. If some application uses multiple data stores, applications that use those data stores are treated as one application.

For example, the management server can decide AP_**01**, AP_**02** and AP_ETL are the composite application by looking up the Server field **16005** and the Data Store field **16010** of the Application Table **7004**. In this case, this composite application uses DR_**01** and DR_**02** as a storage resource, and SVR_**01**, SVR_**02**, and SVR_**03** as a server resource. Resource utilization of the composite application can be decided by the following procedure. For example, the management server can get the resource utilization at time period 2 by looking up the row **7056** and the row **7076** of the Application Table **7004**. The management server can solve the resource utilization by calculating the sum of each server utilization and storage utilization. Server utilization of this composite application is 61 (16+3+42) and storage utilization of this composite application is 189 (50+17+122). In this embodiment, management server can decide the resource utilization by calculating the sum of each server utilization and storage utilization, but the invention is not limited to this. For example, if the some storage area is shared by multiple applications of one composite application, and the management server can detect the amount of the shared area, the management server can exclude the shared area.

A composite application is treated as one application in the fourth embodiment, but the invention is not limited to this. For example, each application of the composite application may be placed in a different cloud. The logical environment (1) **15001** is referred to as an example. The management program **4100** monitors read data amount from DS_**01** and writes data amount to DS_**02**. If the write data amount to DS_**02** is less than the read data amount from DS_**01**, online application AP_**01** and ETL application

AP_ETL may be placed in the private cloud and batch application which is executed periodically may be placed in the public cloud.

In this embodiment, an enterprise can maximize the ROI for IT investment when utilizing a hybrid cloud environment composed of private cloud and private cloud even if a composite application exists.

Of course, the system configuration illustrated in FIGS. **1-3** is purely exemplary of information systems in which the present invention may be implemented, and the invention is not limited to a particular hardware configuration. The computers and storage systems implementing the invention can also have known I/O devices (e.g., CD and DVD drives, floppy disk drives, hard drives, etc.) which can store and read the modules, programs and data structures used to implement the above-described invention. These modules, programs and data structures can be encoded on such computer-readable media. For example, the data structures of the invention can be stored on computer-readable media independently of one or more computer-readable media on which reside the programs used in the invention. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include local area networks, wide area networks, e.g., the Internet, wireless networks, storage area networks, and the like.

In the description, numerous details are set forth for purposes of explanation in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that not all of these specific details are required in order to practice the present invention. It is also noted that the invention may be described as a process, which is usually depicted as a flowchart, a flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged.

As is known in the art, the operations described above can be performed by hardware, software, or some combination of software and hardware. Various aspects of embodiments of the invention may be implemented using circuits and logic devices (hardware), while other aspects may be implemented using instructions stored on a machine-readable medium (software), which if executed by a processor, would cause the processor to perform a method to carry out embodiments of the invention. Furthermore, some embodiments of the invention may be performed solely in hardware, whereas other embodiments may be performed solely in software. Moreover, the various functions described can be performed in a single unit, or can be spread across a number of components in any number of ways. When performed by software, the methods may be executed by a processor, such as a general purpose computer, based on instructions stored on a computer-readable medium. If desired, the instructions can be stored on the medium in a compressed and/or encrypted format.

From the foregoing, it will be apparent that the invention provides methods, apparatuses and programs stored on computer readable media for improving and preferably maximizing the ROI in a hybrid cloud environment. Additionally, while specific embodiments have been illustrated and described in this specification, those of ordinary skill in the art appreciate that any arrangement that is calculated to achieve the same purpose may be substituted for the specific embodiments disclosed. This disclosure is intended to cover any and all adaptations or variations of the present invention, and it is to be understood that the terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with the established doctrines of claim interpretation, along with the full range of equivalents to which such claims are entitled.

What is claimed is:

1. A computer comprising:

a memory; and

a processor being operable to manage private clouds and public clouds by using information stored in the memory, and to manage a migration of a set of an application and a data between the private clouds and the public clouds, the application running on at least one of a server of the private clouds or public clouds, the data to be read or written by the application and being stored in at least one of a storage system of the private clouds or public clouds;

wherein the processor manages the migration of the set of the application and the data between the private clouds and the public clouds based on resource utilization of resources including at least one of the server or the storage system;

wherein the processor is configured to select a set of application and data of private clouds, among a plurality of sets of application and data of private and public clouds, to be migrated, when the resource utilization of the private clouds exceeds a first threshold, so as to keep a high utilization ratio of the private clouds and not to exceed to the first threshold, regardless of a utilization ratio of the public clouds;

wherein the first threshold is defined based on at least one of server usage rate or storage usage rate; and

wherein when the resource utilization ratio of the private cloud exceeds the first threshold, the processor is configured to select for migration from private cloud to a public cloud, among the plurality of applications, an application which is more dynamic than other applications of the plurality of applications;

wherein the application is more dynamic if at least one of following conditions is met: (i) the application has a standard deviation of resource utilization which is larger than the other applications, (ii) the application has a growth ratio of resource utilization which is higher than the other applications, and (iii) the application has a remaining period which is shorter than the other applications.

2. The computer according to claim **1**,

wherein the processor is configured to select a set of application and data of public clouds, among the plurality of sets of application and data of private and public clouds, to be migrated to the private clouds, when the resource utilization of the private clouds falls below a second threshold, so as to keep a high utilization ratio of the private clouds and exceed the second threshold, regardless of a utilization ratio of the public clouds.

3. The computer according to claim **2**,

wherein the processor is configured to select a plurality of sets of application and data of private clouds to be migrated until utilization ratio of the private clouds falls below a third threshold which is lower than the first threshold and higher than the second threshold.

4. The computer according to claim **1**,

wherein updated histories of the plurality of applications are used to determine which application is more dynamic than other applications of the plurality of applications.

5. A computer comprising:

a memory; and

a processor being operable to manage private clouds and public clouds by using information stored in the memory, and to manage a migration of a set of an application and a data between the private clouds and the public clouds, the application running on at least one of a server of the private clouds or public clouds, the data to be read or written by the application and being stored in at least one of a storage system of the private clouds or public clouds;

wherein the processor manages the migration of the set of the application and the data between the private clouds and the public clouds based on resource utilization of resources including at least one of the server or the storage system;

wherein the processor is configured to select a set of application and data of public clouds, among a plurality of sets of application and data of private and public clouds, to be migrated to the private clouds, when the resource utilization of the private clouds falls below a first threshold, so as to keep a high utilization ratio of the private clouds and exceed the first threshold, regardless of a utilization ratio of the public clouds;

wherein the first threshold is defined based on at least one of server usage rate or storage usage rate;

wherein when the resource utilization ratio of the private cloud falls below the first threshold, the processor is configured to select for migration from a public cloud to a private cloud, among the plurality of applications, an application which is more stable than other applications of the plurality of applications;

wherein the application is more dynamic if at least one of following conditions is met: (i) the application has a standard deviation of resource utilization which is larger than the other applications, (ii) the application has a growth ratio of resource utilization which is higher than the other applications, and (iii) the application has a remaining period which is shorter than the other applications.

6. The computer according to claim **5**,

wherein the processor is configured to select a set of application and data of private clouds, among the plurality of sets of application and data of private and public clouds, to be migrated, when the resource utilization of the private clouds exceeds a second threshold, so as to keep a high utilization ratio of the private clouds and not to exceed the second threshold, regardless of a utilization ratio of the public clouds.

7. The computer according to claim **6**,

wherein the processor is configured to select a plurality of sets of application and data of private clouds to be migrated until utilization ratio of the private clouds exceeds a third threshold which is higher than the first threshold and lower than the second threshold.

8. The computer according to claim **5**,

wherein updated histories of the plurality of applications are used to determine which application is more stable than other applications of the plurality of applications.

9. A non-transitory computer-readable storage medium storing a plurality of instructions for controlling a data processor to manage migration among clouds, the plurality of instructions comprising:

instructions that cause the data processor to manage private clouds and public clouds by using information stored in a memory, and to manage a migration of a set of an application and a data between the private clouds and the public clouds, the application running on at least one of a server of the private clouds or public clouds, the data to be read or written by the application and being stored in at least one of a storage system of the private clouds or public clouds;

instructions that cause the data processor to manage the migration of the set of the application and the data between the private clouds and the public clouds based on resource utilization of resources including at least one of the server or the storage system;

instructions that cause the data processor to select a set of application and data of private clouds, among a plurality of sets of application and data of private and public clouds, to be migrated, when the resource utilization of the private clouds exceeds a first threshold, so as to keep a high utilization ratio of the private clouds and not to exceed to the first threshold, regardless of a utilization ratio of the public clouds; and

instructions that cause the data processor, when the resource utilization ratio of the private cloud exceeds the first threshold, to select for migration from private cloud to a public cloud, among the plurality of applications, an application which is more dynamic than other applications of the plurality of applications;

wherein the first threshold is defined based on at least one of server usage rate or storage usage rate;

wherein the application is more dynamic if at least one of following conditions is met: (i) the application has a standard deviation of resource utilization which is larger than the other applications, (ii) the application has a growth ratio of resource utilization which is higher than the other applications, and (iii) the application has a remaining period which is shorter than the other applications.

10. The non-transitory computer-readable storage medium according to claim **9**, wherein the plurality of instructions further comprise:

instructions that cause the data processor to select a set of application and data of public clouds, among the plurality of sets of application and data of private and public clouds, to be migrated to the private clouds, when the resource utilization of the private clouds falls below a second threshold, so as to keep a high utilization ratio of the private clouds and exceed the second threshold, regardless of a utilization ratio of the public clouds.

11. The non-transitory computer-readable storage medium according to claim **10**, wherein the plurality of instructions further comprise:

instructions that cause the data processor to select a plurality of sets of application and data of private clouds to be migrated until utilization ratio of the private clouds falls below a third threshold which is lower than the first threshold and higher than the second threshold.

12. The non-transitory computer-readable storage medium according to claim **9**,

wherein updated histories of the plurality of applications are used to determine which application is more dynamic than other applications of the plurality of applications.

13. A non-transitory computer-readable storage medium storing a plurality of instructions for controlling a data processor to manage migration among clouds, the plurality of instructions comprising:

instructions that cause the data processor to manage private clouds and public clouds by using information stored in the memory, and to manage a migration of a set of an application and a data between the private clouds and the public clouds, the application running on at least one of a server of the private clouds or public clouds, the data to be read or written by the application and being stored in at least one of a storage system of the private clouds or public clouds;

instructions that cause the data processor to manage the migration of the set of the application and the data between the private clouds and the public clouds based on resource utilization of resources including at least one of the server or the storage system;

instructions that cause the data processor to select a set of application and data of public clouds, among a plurality of sets of application and data of private and public clouds, to be migrated to the private clouds, when the resource utilization of the private clouds falls below a first threshold, so as to keep a high utilization ratio of the private clouds and exceed the first threshold, regardless of a utilization ratio of the public clouds; and

instructions that cause the data processor, when the resource utilization ratio of the private cloud falls below the first threshold, to select for migration from a public cloud to a private cloud, among the plurality of applications, an application which is more stable than other applications of the plurality of applications;

wherein the first threshold is defined based on at least one of server usage rate or storage usage rate;

wherein the application is more dynamic if at least one of following conditions is met: (i) the application has a standard deviation of resource utilization which is larger than the other applications, (ii) the application has a growth ratio of resource utilization which is higher than the other applications, and (iii) the application has a remaining period which is shorter than the other applications.

14. The non-transitory computer-readable storage medium according to claim **13**, wherein the plurality of instructions further comprise:

instructions that cause the data processor to select a set of application and data of private clouds, among the plurality of sets of application and data of private and public clouds, to be migrated, when the resource utilization of the private clouds exceeds a second threshold, so as to keep a high utilization ratio of the private clouds and not to exceed the second threshold, regardless of a utilization ratio of the public clouds.

15. The non-transitory computer-readable storage medium according to claim **14**, wherein the plurality of instructions further comprise:

instructions that cause the data processor to select a plurality of sets of application and data of private clouds to be migrated until utilization ratio of the private clouds exceeds a third threshold which is higher than the first threshold and lower than the second threshold.

16. The non-transitory computer-readable storage medium according to claim **13**, wherein the plurality of instructions further comprise:

wherein updated histories of the plurality of applications are used to determine which application is more stable than other applications of the plurality of application.

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